PLANT REGENERATION FOLLOWING FIRE IN BUNGENDORE PARK, BEDFORDALE, WESTERN AUSTRALIA

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ABSTRACT

The results of a study of plant regeneration following fire in Bungendore Park, Bedfordale, Western Australia are presented. The seven-year study examined aspects of tree mortality, understorey species reappearance and effects on the orchid community. Mature Jarrah and Marri trees displayed epicormic regrowth within 6 months of the fire. Saplings regenerated from coppice 1–2 years later. Wandoo mortality exceeded that of Jarrah and Marri and was slower to regenerate. For all three tree species, saplings showed greater susceptibility to fire than mature trees and highest tree mortality was recorded in areas of highest fire intensity. Less than average post-fire rainfall probably accounted for low seedling numbers of Jarrah, Marri and Wandoo. *Allocasuarina fraseriana* regenerated very successfully via epicormic and crown regrowth regardless of age or size of tree. *Banksia grandis* displayed the greatest tree mortality with 31% of recorded trees failing to recover.

197 of the 352 species known from Bungendore Park reappeared at some time during the study period. Vegetation type, fire intensity and fire history influenced the type and density of species more than species diversity. Regenerating species were not widespread within the Park, only 6 % being recorded from seven or more quadrats. Species diversity peaked 2–3 years after the fire. Regeneration mechanisms for recorded understorey species are discussed (55 % are resprouters) and this is related to fire frequency and fire management strategies. Reappearing leguminous species were widespread and in high densities, but showed signs of dying off 6–7 years after the fire. Some understorey species took 2–3 years to reappear.

Within 12 months of the fire, sixteen new records of orchid species had been made and a greatly increased abundance of fire-stimulated orchid species was recorded. Orchid species numbers showed a steady decline in subsequent years to lower than pre-fire levels.

INTRODUCTION

Bungendore Park (↑A4561) is an "A" class reserve of approximately 500 hectares located about 5 kilometres by road from the City of Armadale along the Albany Highway. The park is situated on the western edge of the Darling Plateau and because it includes the upper parts of the Darling Scarp, displays a wide range of soils, topography and vegetation types resulting in a rich, diverse flora. It lies immediately to the north of Wungong Gorge and the Wungong Dam, already a major recreational resource in the area and, as a result, Bungendore Park forms a useful extension of this important natural feature. Bungendore, an aboriginal name meaning "Place of Gum Blossom", forms one of the attractions on the Heritage Country Tourist Drive – Route 205.

Whilst most of its 498 ha. is found on the undulating lateritic uplands of the plateau at elevations of up to 280 m, the western edge of the park encompasses the steep mid and upper slopes of the Darling Scarp. The park's northern boundary slopes gently towards Neerigen Brook and the eastern boundary forms part of the gentle slopes of the upper Wungong valley. To the south, the edge of the park is found at the top of the steep northern slope of the Wungong Gorge. In the areas around major drainage lines, especially Cooliabberra Spring, great variations in soil composition, depth and temperature (due to slope aspect and angle variations) occur resulting in a complex mosaic of vegetation types. Five major vegetation complexes based on Heddle *et al.* (1980) can be found within the park. Open Jarrah-Marri forest dominates (occupying about 80% of the park) and is found on gravelly soils of the gently undulating uplands of the lateritic plateau. Small areas of Wandoo-Marri woodland are located on the younger, shallower soils to the west on the slopes surrounding Cooliabberra Spring. Outcrops of granite on the lower slopes of this creek are surrounded by heath. Herbland covers the surface of the exposed granite. Finally, in the south-western corner is a low open woodland of Rock Sheoak (*Allocasuarina huegelii*), also associated with granite outcrops.

A survey of the flora of Bungendore Park was made between 1991 and 1993. A total of 352 species from 167 genera and 63 families was recorded representing about 44% of the total species occurring in the Jarrah forest of the south-west of Western Australia (Bell and Heddle 1989). One declared rare plant species and three listed "priority" species (Hopper *et al.* 1990) were recorded for the park.

On 9 December 1994, an uncontrolled wildfire swept into the park from the Wungong Gorge and moved rapidly through over 85% of the park, razing the understorey to an ash bed and reducing the dominant trees to blackened trunks. Flames were reported to have reached 10 to 15 metres above the trees. Many animals died in the fire and the destruction of much of the natural habitat meant that many animal species might never return. Local plant extinctions were also possible because fires occurring at the wrong times of year or with an inappropriate frequency destroy flowers and immature seeds and seedling germination is not stimulated (Australian House of Representatives 1984).

Fire, however, is an integral part of the Australian environment and is often essential in the maintenance of many of our ecosystems. Native plants have not only evolved mechanisms to cope with fire, but many have come to depend on high intensity fires for their survival (such as the hard-seeded leguminous species which need heat to germinate). Other fire adaptive traits include re-sprouting from stems and roots using epicormic shoots (e.g. Eucalypts, Banksias and sheoaks), lignotubers (and other underground storage organs), basal sprouts (e.g. Hibbertias, Leucopogons, Hakeas and Grevilleas) and large protected apical buds (Zamia and Balga) (Photo 1.). Some other plants rely on soil-stored seed, protective bark, woody fruits, or fire-stimulated flowering (e.g. orchids and Balga) (Burrows 1985). In forests such as that found in Bungendore Park about 70–75% of all understorey species re-sprout following fire; the remainder relying on soil- or canopy-stored seed (Burrows 1997).

South-Western Australia, with its dry Mediterranean climate, has been subjected to a relatively high natural fire frequency from lightning strikes (accounting for 194 fires in the SW forests between 1987 and 1992 (Ward and Sneeuwjagt 2000) and Aboriginal bush burning; the pre-European frequency estimated to be 3 to 4 fires per decade. Forty years ago, however, the newly formed Forests Department introduced a programme of prescribed and controlled fuel reduction burning as a measure of reducing the frequency and severity of wildfires (Burrows 1985). Since its introduction, no major bushfires of the type which devastated Dwellingup in 1961 have occurred (Burrows 2000 a.). It is known, however, that the frequency, intensity and season in which prescribed burns occur can have an effect on the ecology of an area, especially in small isolated areas of remnant bushland, resulting in the loss of some fire-sensitive species from the population and increased weed invasion (Australian House of Representatives. 1984). On the other hand, the health of a forest can be enhanced by an occasional hot burn which stimulates nitrogen fixing leguminous species to germinate from soil-stored seed (Shea *et al.* 1979) and cleanses and sterilizes the soil (Australian House of Representatives 1984). Modern fire management policies attempt to provide protection to life and property whilst being ecologically sustainable and enhancing biodiversity (Burrows 2000 b.).

Small sections of Bungendore Park have been subjected to prescribed burning on a rotational basis for many years now, resulting in a mosaic of fire

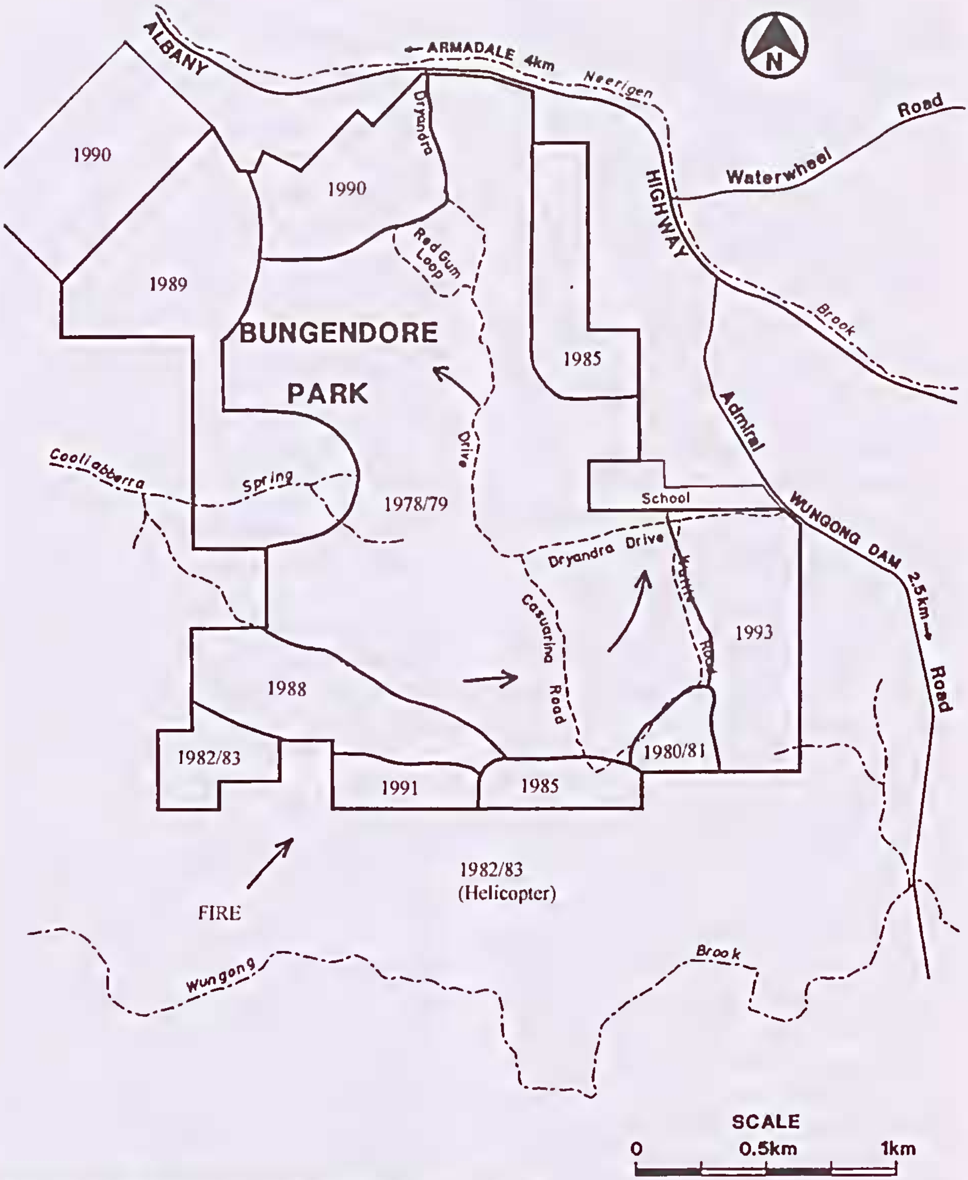


Figure 1. Fire History of Bungendore Park.

history in the park ranging from one year prior to the 1994 wildfire to 16 years (Figure 1). It is not known how long ago the last wildfire went through the park. This study looks at three aspects of vegetation regeneration in the park after the 1994 fire:

- Tree mortality
- Understorey species reappearance

- Effects of fire on the orchid community in the park

METHOD

TREE MORTALITY

The aim of this aspect of the study was to assess the effect of a wildfire on the survival of the main dominant and understorey tree species found in the park. A vegetation map based on Havel's site-vegetation type classification system, produced for my 1999 survey of Bungendore Park, (Figure 2) was used to plan the location of ten 100m x 100m

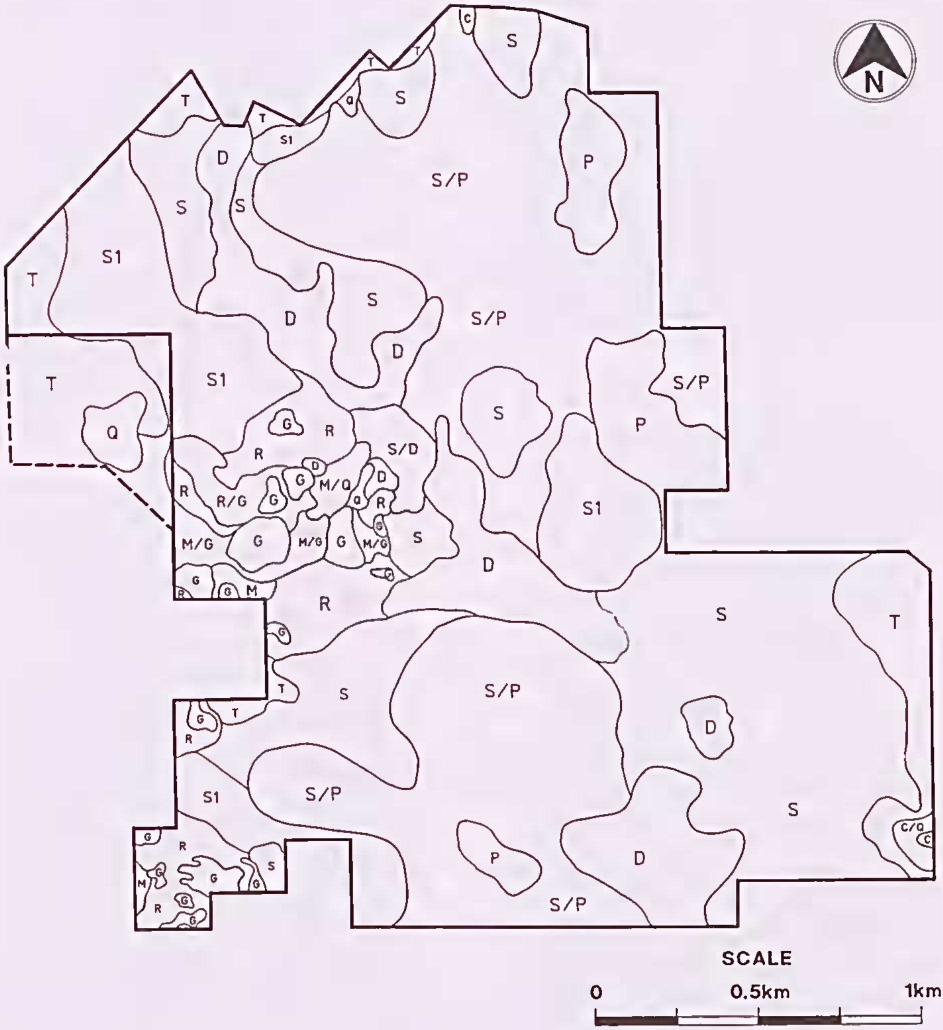


Figure 2. Distribution of Site-Vegetation Types (based on Havel 1975 a and b) (after Lewis 1999)

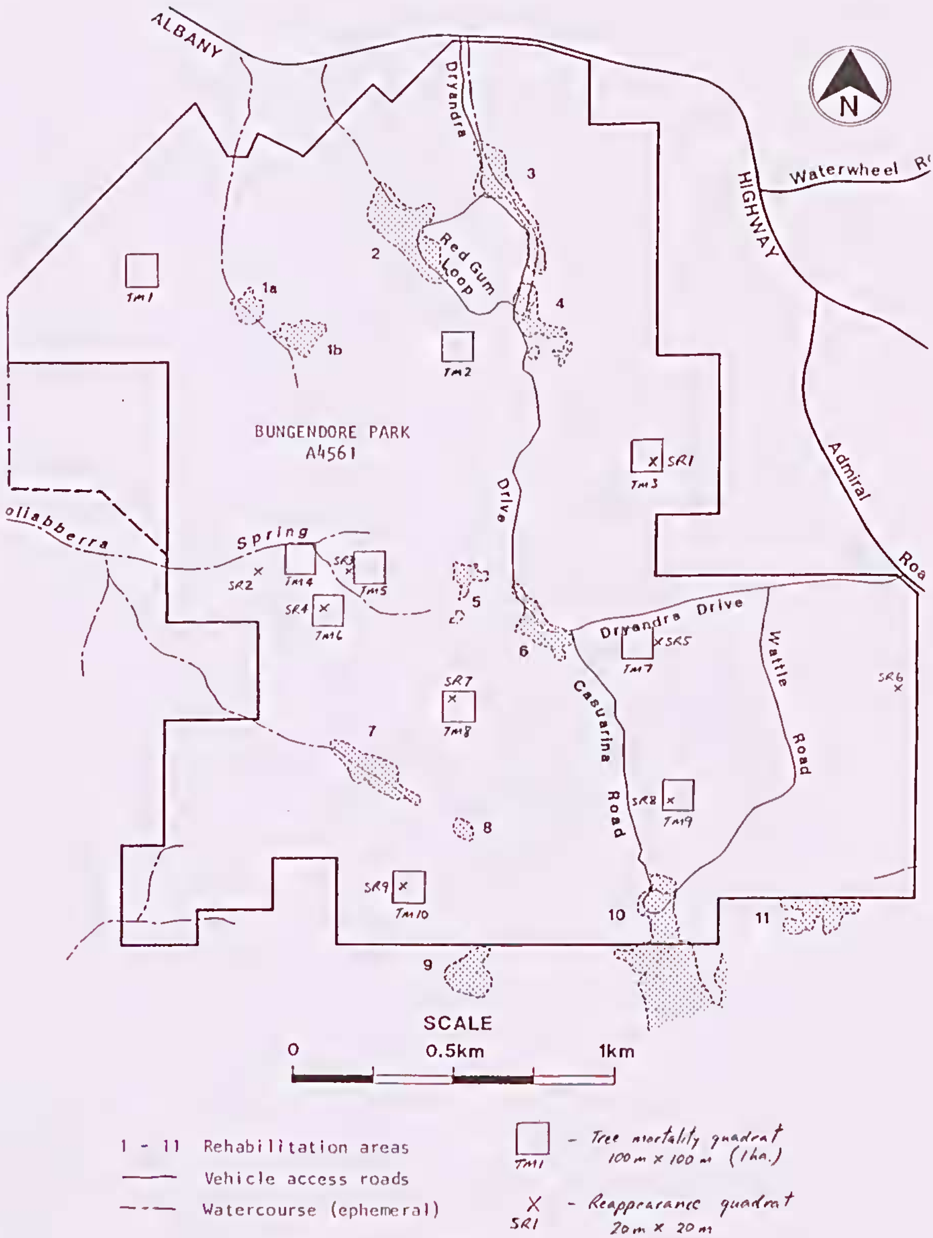


Figure 3. Tree Mortality and Species Reappearance Quadrat Locations.

quadrats in two of the three main vegetation types within the park (open Jarrah-Marri forest and Wandoo-Marri woodland). These ten quadrats were located widely throughout the park (Figure 3) in

Photo 1. Apical regrowth from *Xanthorrhoea preissii*

Photo 2. Deeply fissured Marri bark

Photo 3. Wandoo coppice regrowth.

Photo 4. Discarded epicormic regrowth on Jarrah.

Photo 5. Marri saplings showed greater mortality than mature trees.

Photo 6. Bark loss on mature Jarrah. (4 years after fire).

Photo 7. Wandoo sapling thicket

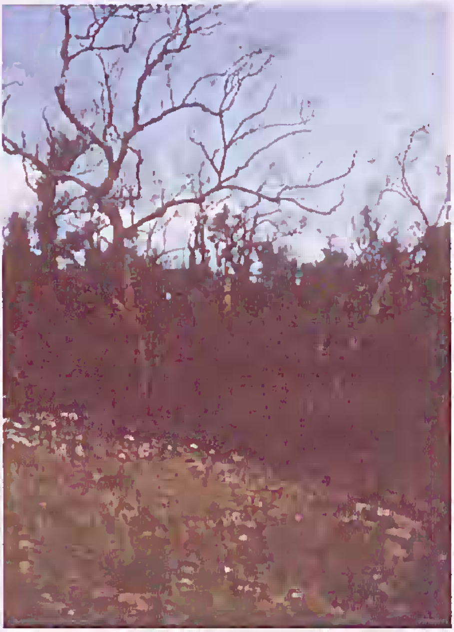
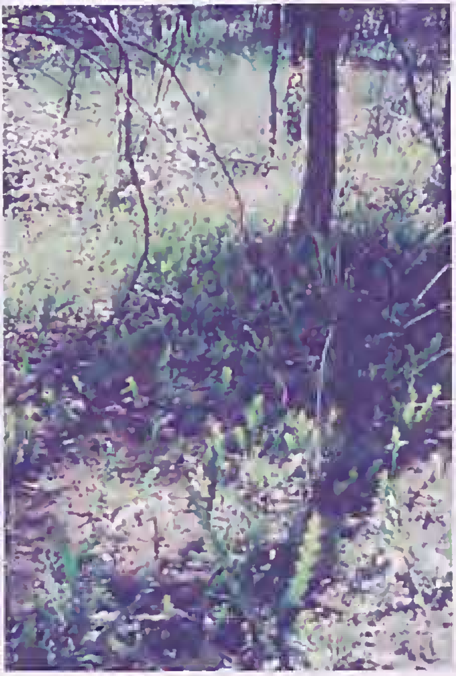


Photo 8. Epicormic regrowth on mature Wandoo.

Photo 9. *Allocasuarina* survive fire, but in poor condition.

Photo 10. Regrowth in *Allocasuarina* is by epicormic shoots.

Photo 11. Young Banksias survive fire better than mature trees.



Photos 12 and 13. Rapid high density regeneration of the legumes *Acacia pulchella* and *A. alata*

Photo 14. *Acacia alata* thicket (3 ½ years after fire)

Photo 15. Same thicket of *Acacia alata* dying off (6 years after fire).

Photo 16. *Acacia pulchella* dying off in species reappearance quadrat number 3. (6 years after fire).

Photo 17. Dense *Acacia lateriticola* regeneration in species reappearance quadarat number 9. (3 ½ years after fire).

Photo 18. Fire-stimulated flowering in *Xanthorrhoea preissii*.

Photo 19. Fire-stimulated flowering of redbeaks (*Pyrorchis nigricans*).

order to encompass a variety of fire history regimes. Each quadrat was visited on four occasions over a seven-year period. Tree mortality was assessed by determining the number of standing dead trees within each quadrat and recording their position so they could be relocated at a later date. For one of the ten quadrats, height, diameter at breast height and scorch height were also noted for each of the recorded dead trees. Records were made for the three dominant tree species found in the park – Jarrah (*Eucalyptus marginata*), Marri (*Corymbia calophylla*), and Wandoo (*Eucalyptus wandoo*). The understorey tree species *Allocasuarina fraseriana*, *Banksia grandis* and two species of *Persoonia* (*P. elliptica* and *P. longifolia*) were also recorded. Trees which showed neither basal sprouts nor epicormic regrowth were scored as dead on the initial visit. If, on subsequent visits, any form of regrowth was present, including coppice, the tree was recorded as having recovered. A total of 5882 trees were scored, mainly (4955 individuals) Jarrah, Marri and *Banksia grandis*.Tree mortality data were then examined to establish any relationships between tree deaths, tree species, regeneration method, fire intensity and vegetation type.

SPECIES REAPPEARANCE

This aspect of the study was designed to record the post-fire regeneration of understorey species and thus be able to assess the effect of a wildfire on the number (species density) and type (species diversity) of these species occurring in Bungendore Park. Nine permanent 20m x 20m quadrats were established in the park within three months of the December 1994 wildfire. Based on a vegetation map of the park, the quadrats were located to ensure that all three main vegetation types in the park (open Jarrah-Marri forest, Wandoo-Marri woodland and heath) were included at least twice (Figure 3). Each quadrat was visited on five separate occasions over a period of seven years following the fire (all quadrats twice in 1995, the year immediately after the fire). Each quadrat was subdivided into 400 1m x 1m units and presence of each understorey species appearing within each unit of the quadrat was recorded. In one quadrat, the total number of individuals of two of the more common species (*Hibbertia hypericoides* and *Acacia lateriticola*) was recorded. These data were entered onto a computer spreadsheet so that numerical information such as species diversity, species density, new records for subsequent visits and the disappearance of previously recorded species could easily be made. The post-fire regeneration strategy for each species was determined based on the categories established by Burrows (1994). Data were examined to identify any relationships between species re-appearance, fire intensity, vegetation type and regeneration strategy.

ORCHID SURVEY

A species list of orchids for Bungendore Park existed from a survey made prior to the 1994 wildfire. The effect of fire on orchid flowering, however, is well known and documented and so this fire presented an opportunity to collect data on fire-stimulated species which may occur in the park and to assess any long-term effects of a high intensity fire on the Park's orchid community. Information on the presence of orchid species in the park after the fire was collected from a variety of sources. Some orchid species were observed within the nine "species reappearance" quadrats. These quadrats, however, although being positioned in all major vegetation types within the park, represented a relatively small area of the 498 ha. reserve. Further records of post-fire orchid flowering were obtained from ground traverses in areas of the park known to have previously presented many orchid species plus anecdotal evidence from regular park visitors. Information collected was used to assess the effect of the wildfire on orchid species diversity and abundance, especially for fire-stimulated species. The appearance of orchid species known to flower only after fire was also recorded.

FIRE HISTORY AND INTENSITY

Records and anecdotal information provided by the local volunteer fire brigade headquarters were used to produce a fire history map of Bungendore Park. A colour aerial photograph taken 41 days after the wildfire of December 9 1994, along with ground observations, was then used to make a fire intensity map of the park using subjective categories (high, medium and low) (Figure 4). This provided information which could be used to relate fire intensity to fuel loads, vegetation types and any patterns which might emerge from data collected on tree mortality, species reappearance, density and diversity (richness).

RESULTS AND DISCUSSION

TREE MORTALITY

Eucalypts are well adapted to withstand fire. Their bark is a good insulator against heat and so bark thickness is of considerable importance (Hingston 1985). Variations occur in thickness, however, due to a rough texture and the presence of furrows. Both Jarrah and Marri have a thick rough outer bark layer. Marri bark, however, is deeply fissured (Photo 2) and would be expected to offer less protection to the sensitive underlying (living) cambial layer which is killed by temperatures as low as 65ºC (Luke and McArthur 1978). Marri mortality would therefore be expected to be higher than Jarrah as was found by Kimber (1971) in a study carried out after the devastating 1961 Dwellingup fire (McCormick 1971). When considering all ten quadrats together, mortality numbers for

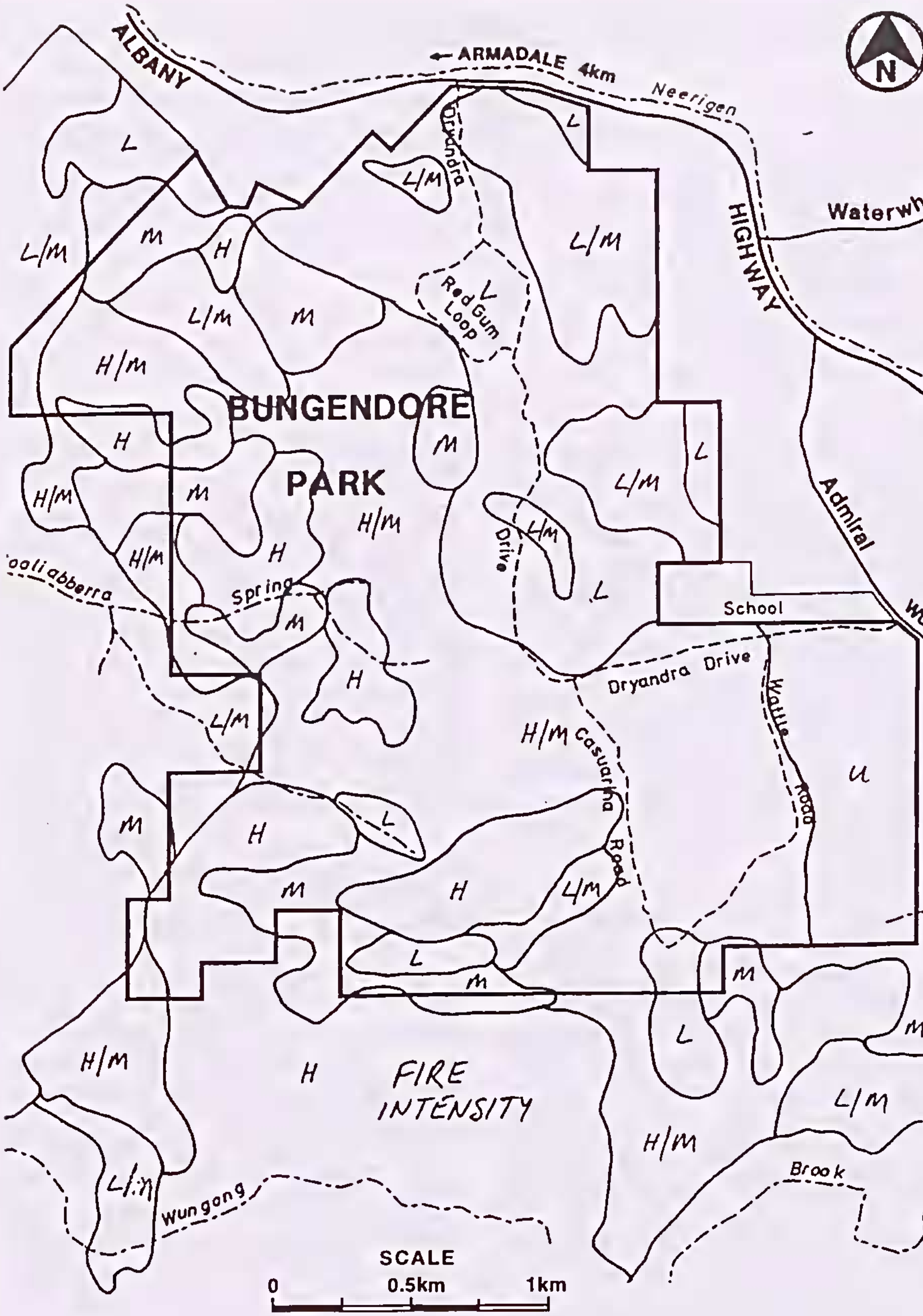


Figure 4. Fire Intensity (H = high, M = moderate, L = low, U = unburnt) Drawn from January 1995 aerial photograph.

Table 1. Tree Mortality (all quadrats combined)

	Species	Total No. trees recorded from ten 100m x 100m quadrats	% dead (<6 months after fire)	% dead (>12 months after fire)
a	*Corymbia calophylla*	1798	3.3	1.6
b	*Eucalyptus marginata*	1698	7.4	2.6
c	*Eucalyptus wandoo*	635	20.3	9
d	*Allocasuarina fraseriana*	280	5	0.7
e	*Banksia grandis*	1459	38	31
f	*Persoonia longifolia*	10	40	0
g	*Persoonia elliptica*	2	0	0

Jarrah exceed those for Marri (Table 1). If the quadrats are considered separately, however (Table 2), mortality numbers for only four of the ten quadrats were higher for Jarrah. Furthermore, re-sampling of all quadrats from 12 months up to 6 years after the fire showed a greater decrease in recorded dead trees for Jarrah than Marri as regeneration got underway. All tree species showed a decrease in recorded deaths in subsequent re-sampling of the quadrats.

In Jarrah and Marri, mature trees were the first to display regrowth (most within 6 months using epicormic shoots) whilst saplings regenerated mainly from coppice regrowth some time later (1–2 years). In Wandoo, only the larger, more mature trees displayed epicormic regrowth, most coppicing from the base (Photo 3). Epicormic shoots on many of the larger Marri and Jarrah trees died and fell off within 12 months (Photo 4) as if regeneration had begun but failed, possibly due previous tree damage or the fire occurring at the beginning of summer with no substantial rains to follow (Table 3).

Drought can affect regeneration (Hussey and Wallace 1993). Crown regrowth in most of these individuals, however, continued to flourish as epicormics lower on the tree serve only to maintain the tree in the short term while crown regrowth is established (Luke and McArthur 1978). One Wandoo was recorded dead two years after having displayed epicormic regrowth initially and then failing to maintain any crown or coppice foliage (Tree mortality quadrat TM 6).

Tree mortality decreases with size of tree (Williams 1995, and Burrows 1987). Consequently, saplings usually show greater mortality than larger trees (Shea *et al.* 1979) (Photo 5). Quadrat No. 6 had a large number of individual trees (1247), most of which were Marri (1035) and a high proportion with a diameter at breast height (dbh) of <10cm. Furthermore, this quadrat occurred towards the centre of the park which had not been burnt for 16 years and was in a high/moderate fire intensity region (estimated to be >4000

Table 2. Tree Mortality (individual quadrats)

	Quadrat Number														
	1			2			3			4			5		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
a	55	2	2	198	6	5	13	7	0	53	2	2	112	1.8	1.8
b	173	10	4	342	5	3	81	10	2.5	–			4	75	25
c	–			–			–			250	13	5	353	24	13
d	–			55	0	0	171	6	0	–			–		
e	339	21	9	153	55	46	6	0	0	–			–		
f	–			–			–			–			–		
g	–			–			–			–			–		

	Quadrat Number														
	6			7			8			9			10		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
a	1035	0.5	0.5	61	8	5.5	61	18	0	10	10	10	200	9.5	3
b	180	4.5	3	179	5	2	311	13	2.5	142	7	3	286	4.5	0.6
c	32	0	3	–			–			–			–		
d	–			–			54	5.5	3.7	–			–		
e	–			46	69	59	458	51	44	226	46	41	66	50	36
f	–			–			10	40	0	–			–		
g	–			–			2	0	0	–			–		

Legend:

- A: Total Number of trees in quadrat
- B: Percentage of trees recorded dead within 6 months
- C: Percentage of trees recorded dead after 12 months

Species Key:

- a. *Corymbia calophylla*
- b. *Eucalyptus marginata*
- c. *Eucalyptus wandoo*
- d. *Allocasuarina fraseriana*
- e. *Banksia grandis*
- f. *Persoonia longifolia*
- g. *Persoonia elliptica*

Table 3. Monthly rainfall for Bedfordale.

Month	Dec 1994	Jan 1995	Feb 1995	Mar 1995	Apr 1995	May 1995	June 1995	July 1995	Aug 1995	Sept 1995
Rainfall received (mm)	0.8	0.4	8.8	1.0	15.2	168.6	158.6	292.6	107.4	86.3
Average (last 8 years) (mm)	11.7	20.1	3.4	25.7	30.4	119.1	177.3	208.3	164.3	119.1

kW/m). Photo 6 provides further evidence of the fire intensity in this quadrat as large sheets of bark peel from a large Jarrah showing the extent of cambial damage during the fire (Abbott and Loneragn 1983). Baird (1977) reported that fire-induced cambial damage in Marri often took 3–4 years to become evident through bark loss. Tree mortality for this quadrat was very low (Marri = 0.5%, Jarrah = 3%). It should also be noted that very few saplings showed epicormic regrowth and regenerated only from rootstock coppice, indicating that the original bole was killed or severely damaged. Trees older than 5 years usually have lignotubers large enough to coppice successfully which appears to be the case in this quadrat.

Jarrah seedling emergence is greatest when leaf litter and understorey species are removed such as after fire (Stoneman and Dell 1994). Very few seedlings of either Marri or Jarrah were recorded from any of the quadrats. With respect to rainfall, December 1994 and January 1995 were both below average followed by an above average February and then two more well below average months (Table 3). Seed germination may have been stimulated by the February 1995 rain but failed to progress in the subsequent two dry months. Alternatively, low numbers of Jarrah and Marri seedlings may be due to seed removal by vertebrate and invertebrate fauna seed harvesting by birds, rodents and ants has significant effects on seedling emergence of Jarrah (Stoneman and Dell 1994).

Tree mortality was higher for Wandoo than for either Jarrah or Marri (Tables 1 and 2). Without a protective layer of thick rough bark, Wandoo trees appear to be more susceptible to high intensity fires. Burrows *et al.* (1990) reported death, severe bole damage and bark loss in Wandoo trees in a high intensity (about 2000 kW/m) section of a prescribed burn south-east of Perth (Burrows *et al.* 1990). Kimber (1971), however, found that Jarrah suffered no bole damage from fires intense enough to cause crown damage (McCormick 1971). Complete defoliation of Wandoos occurred in quadrats 4 and 5 which contained the majority of Wandoo trees in Bungendore Park. Furthermore, these quadrats were located on a steep west-north-west facing slope at the top of the scarp and fires are known to spread more rapidly up steep slopes (Hussey and Wallace 1993). In this region the fire was driven along and up the slope by winds from the south-west. High intensity fires are the most likely consequence of a long unburnt area is due to the fact that as time goes by (20–25 yrs), the fuel load contains less leaf litter and more bark, branches, boles and fruits (Western Australian Fire Review Panel 1994). Consequently, this area probably experienced the highest fire intensity in the park (estimated to be well above 4000 kW/m). In this study, as in that of Burrows (Burrows *et al.* 1990), Wandoo regeneration and seedling germination occurred in a clumped distribution, probably associated with ashbeds (forest soils which have been exposed to very high temperatures for a prolonged period during the combustion of heavy fuels such as logs and limbs). Wandoo regeneration away from ashbed was recorded by Burrows *et al.* (1990) to be poor in site-vegetation type M. Both tree mortality quadrats TM 4 and TM 5 were classified as vegetation site type M and several large fallen Wandoo trees smouldered for many days within one of these quadrats (TM 5) (Photo 7). Dense thickets of Wandoo saplings can now be found here.

When considering individual quadrats for Wandoo tree mortality, highest mortality occurred in that located in the highest fire intensity area (TM 5) (24 % dead on initial visit falling to 13 % after three years). Wandoo mortality in TM 4 was slightly less than that in TM 5 (falling from 13 % to just 5% after three years), probably because TM 4 is in a moderate fire intensity area and had been control burned just 5 years previous. Interestingly, TM 6 for which an unusually low Marri sapling mortality was recorded, also contained 32 Wandoo trees, none of which was recorded dead (Table 2).

Much of the regrowth of Wandoo was either by coppice shoots (including many of the larger trees with a dbh>20cm) or small numbers of seedlings. Only large, mature trees displayed epicormic shoot regrowth (Photo 8). Wandoo were slower to produce leaves from epicormic shoots than Jarrah or Marri, most appearing well after 6 months.

Wandoo seed regeneration is favoured by dry autumn fires and needs ashbeds for germination (CALM 1994) and so fewer than expected seedlings were recorded in this study, probably due to the timing of the fire. Ashbeds remain, however, for up to 2–3 years (Burrows 1983), so despite the timing of this fire, Wandoo seedlings continued to appear in subsequent years.

Allocasuarina trees are often badly damaged by fires but survive in poor condition such as with hollowed trunks or untidy and sparse canopy foliage (Baird 1983) (Photo 9). Three quadrats contained a total of 280 individuals of *Allocasuarina fraseriana*, only two trees failing to regenerate in a High/Moderate fire intensity quadrat unburnt for 16 years. Regrowth in this species was almost entirely via epicormic shoots along the trunk and in the crown (Photo 10). Both young and older trees resprouted vigorously.

Banksia grandis, especially older trees, appears more susceptible to fire than any other tree species in Bungendore Park. Moderate to high intensity fires (600–1500 kW/m) will kill younger plants (dbh <5 cm) to the ground (but these readily re-shoot from lignotuber) while older trees (dbh >12 cm) are killed outright (Burrows 1983). Shea *et al.* (1979) reported a *Banksia grandis* mortality of 20%, 20 months after a 4000 kW/m controlled burn near Dwellingup (whilst recording only 0.8% for Jarrah and 1.7 % for Marri in the same plot). 31%

Table 4. Quadrat burn details and site-vegetation type

Tree mortality quadrat No.	Fire intensity (H, M, L)	Years since last burn	Site vegetation type
TM1	½ H/M and ½ L/M	5	S (variant)
TM2	½ L and ½ H/M	16	S/P
TM3	L/M	16	P
TM4	M	5	M/G
TM5	½ H and ½ H/M	16	M/G
TM6	H/M	16	R
TM7	H/M	16	S
TM8	H/M	16	S/P
TM9	H/M	16	S/D
TM10	L	3	S (variant)

mortality was recorded from the seven quadrats containing *Banksia grandis* in Bungendore Park. Four of these quadrats (TM's 2, 7, 8 and 9) had very similar fire details (High/Moderate intensity and unburnt for 16 years – Table 4). In these quadrats, *Banksia grandis* mortality was high initially and remained high for subsequent visits. These quadrats also contained a greater number of older *Banksia* trees and the deaths of these appear to be largely responsible for the high mortality rates recorded here (Photo 11. showing old dead Banksias and healthy seedling Banksias in TM 8.). The regenerative capacity of *Banksia grandis* lignotubers appears to decrease with age and size of tree. Quadrats which showed a greater reduction in *Banksia grandis* mortality for subsequent visits were those in low fire intensity areas and which had been burned <5 years ago (TM's 1 and 10). In his study, Shea *et al.* (1979) also reported that seedling Banksias had re-established in many areas since the fire.

Banksias are highly susceptible to the Jarrah dieback fungus (*Phytophthora cinnamomi*) and the use of high intensity fires to reduce the *Banksia* population in a forest as a means of controlling the disease has been suggested. Intense wildfires have a sterilizing effect on the soil and greatly reduce the populations of soil microbiota (Australian House of Representatives 1984). Restrictions on vehicle movement and horse riding have kept the spread of dieback disease through Bungendore Park to a minimum and evidence of the disease is found mainly in and around previously disturbed areas such as disused gravel pits. As a result, and perhaps also from the effect of large numbers of *Acacia pulchella* which is known to suppress the activity of the dieback fungus (CALM 1994), the majority of the park remains relatively dieback-free. It would, however, take several high intensity fires to achieve the effect of controlling dieback through the reduction of the *Banksia grandis* population and no significant reduction in the density of *Banksia* understorey would be achieved from a single high intensity fire (Shea *et al.* 1979). Nevertheless, from the point of view of forest health, infrequent high intensity hot summer fires such as the 1994 wildfire in Bungendore are likely to be of long-term benefit due to some degree of soil cleansing and a flush of nitrogen-fixing legume species. Such fires are ecologically desirable (Burrows 1983) although Jarrah trees may suffer from hot fires which kill cambial tissue, sapwood and the outermost hardwood as this produces a scar that allows fungus to enter the tree which then allows termites to follow (Perry *et al.* 1985).

Neither of the two *Persoonia* species (*P. elliptica and P. longifolia*) was killed by the fire. Individuals of these species regardless of their location with respect to fire intensity or history all showed healthy epicormic regrowth in the upper trunk and crown.

SPECIES REAPPEARANCE

PART 1: OVERALL REAPPEARANCE

352 species are known to occur in Bungendore Park. Over the 7-year period of data collection, a total of 197 species were recorded to have re-appeared at some time during the study.

No single quadrat contained a significantly greater number of re-appeared species than other quadrats (Table 5), although the suite of species recorded from each plot varied depending on the vegetation type, fire intensity and fire history. The number of species re-appearing in each plot (average of 56 species per quadrat) was substantially lower than the total of 197 recorded for all plots over the 7-year study period, suggesting that to get a comprehensive list of reappearance species many sample quadrats in a wide variety of vegetation types is required.

Nearly half (48%) of all species

Table 5. Quadrat Species Reappearance, fire details and Vegetation Type.

	Species Reappearance Quadrat Number								
	1	2	3	4	5	6	7	8	9
Site vegetation type	P	G	G	R	S	T	S/P	D	S/P
Fire intensity	L/M	H	H	H/M	H/M	L	H/M	H/M	L
Years since last burn	16	5	16	16	16	1	16	16	3
Number of species recorded	54	65	58	66	49	33	63	58	64

recorded could be found in a single quadrat. Very few of the species recorded were found to be widely represented in the sample sites, only 11% being recorded from six or more of the quadrats and this figure dropping to just 6% recorded from seven or more quadrats. *Hibbertia hypericoides* was the only species recorded from all nine quadrats. Four species (*Eucalyptus marginata*, *Phyllanthus calycinus*, *Xanthorrhoea preissii* and *X. gracilis*) were located in eight quadrats. The next most widespread species were *Acacia pulchella*, *Chamaescilla corymbosa*, *Dryandra lindleyana*, *Hibbertia commutata*, *Lechenaultia biloba*, *Lomandra preissii* and the common weed *Oxalis pes-caprae* which were recorded from seven of the nine quadrats. There appears to be no relationship between the total number of species re-appearing (species diversity) and either vegetation type, fire intensity or time since last burn. These factors probably have a bigger influence on the type of species appearing after a fire and the densities with which these species re-appear.

Quadrat 6 contained the lowest number of species. This site was not burnt in the 1994 wildfire but rather was subject to a prescribed burn just one year before. Consequently, it was not sampled until the end of the study period when it would display a more consistent suite of species. This, however, was after the post-fire peak in species richness known to occur between 3 and 5 years (Burrows 2000 b.). Secondly, the quadrat was sampled in summer and many ephemeral species may not have been evident.

PART 2: REGENERATION STRATEGIES

Bungendore was a high intensity summer fire and the response mechanisms of different plant species varies depending on season, intensity and frequency. (Lamont 1985 and Hobbs 1995) (although van der Moezel suggest that these mechanisms may be adaptations produced in response to other environmental factors such as drought or insect attack) (van der Moezel *et al.* 1987). Previous studies of fire regeneration in the Jarrah forest have found that about 70 % of all understorey species on drier, upland sites resprout following fire, the remainder regenerating from seed stored in the soil or in woody fruits in the canopy (Burrows 1997). Higher numbers of seeder species are found in seasonally moist sites such as creek lines. Quadrats 2 and 4 contained the greatest percentage of seeders (Tables 6 and 7). One of these plots included exposed granite outcrops which retain moisture around their margins and the other was sited alongside a major drainage line in the park (Cooliabberra Creek) which flows in winter. *Acacia pulchella* and *Acacia alata* regenerated rapidly and profusely at these locations and high species densities were recorded for these two species (Photos 12, 13 and 14). Both these quadrats were located in High/ Moderate fire intensity areas, conducive to legume germination and seedling establishment (hot fires also increase seed production) (Skinner 1984). There is also a very large ant population in this area

Table 6. Broad Regeneration Strategies.

	Species Reappearance Quadrat Number									
	All quadrats	1	2	3	4	5	6	7	8	9
Regeneration Strategy	% of species using strategy									
Seeders	21.5	19	28	18	28	11	16	22	22	17
Sprouters	55	79	42	50	57	71	70	61	68	71
Geophtyes	22	28	28	28	13	17	9	16	11	10

Table 7. Specific Regeneration Strategies.

	Species Reappearance Quadrat Number									
	All quadrats	1	2	3	4	5	6	7	8	9
Regeneration Strategy	% of species using strategy									
2	19	19	23	18	28	11	16	18	22	17
4	5	8	5	5	8	6	6	7	4	7
5	41	61	32	33	39	51	42	38	48	54
6	4.5	5	0	5	4	6	13	11	6	5
7	2	5	5	7	6	8	9	5	4	5
8	2.5	0	5	0	0	0	0	4	0	0
9	2.5	0	0	0	0	0	0	0	4	0
10	1.5	0	2	2	0	0	3	0	0	0
11	22	28	28	28	13	17	9	16	11	10

Regeneration Strategy Key: (after Burrows 1994)

- 2 – killed by 100 % scorch, uses soil-stored seed
- 4 – survives 100 % scorch, soil suckers
- 5 – survives 100 % scorch, basal sprouts
- 6 – survives 100 % scorch, epicormic shoots
- 7 – survives 100 % scorch, large apical bud
- 8 – killed by 100 % scorch, uses seed (from soil or canopy)
- 9 – survives 100 % scorch, uses 4, 5, 6, 7, or 11
- 10 – uses spores (ferns)
- 11 – geopyhtes (surviving 100 % scorch, re-sprouting from underground storage organs).

which may have harvested a substantial underground reservoir of seed. Unlike woody trees and shrubs which survive for a long time after resprouting, however, obligate seed species such as some species of *Acacia* and other legumes which regenerate in large numbers after a hot summer fire tend to die within 7 –10 years.

(Burrows 1997). Both these species (*Acacia pulchella* and *A. alata)* showed signs of dying off after 6–7 years (Photos 15 and 16).

The response of leguminous species to fire is well documented. Shea *et al*. (1979) found that legume regeneration rarely followed 20 – 150 kW/m prescribed burns and more usually occurred after high intensity fires. He also noted that legume species had decreased in the forest as a result of prescribed burns. Burrows (1983) concluded that legumes needed dry soil (which allows better heat penetration) (Hussey and Wallace 1993), a large quantity of ground fuel and no subsequent drought, grazing or competition in order to regenerate successfully as these hard seeded species such as *Acacia* need hot fires to crack the seed coat. Many of these conditions were met by the 1994 fire in Bungendore Park and possibly helps to explain why the park has a large number of legumes and a low incidence of Jarrah dieback.

The benefits of legume regeneration to a forest are that they fix atmospheric nitrogen and so play an important role in forest fertility whilst encouraging the return of native mammal species (Shea *et al*. 1979), and many species such as *Acacia pulchella* produce fungus inhibiting micro-organisms which reduce the susceptibility of other dieback sensitive species to infection (Skinner 1984). Most legumes will, however, complete a useful lifecycle and achieve peak seed production within 6 years (Skinner 1984) and changes in species composition, density and diversity after fire are probably short lived (<10 years) as legumes die off. An occasional hot summer burn is, therefore, desirable in the Jarrah forest in order to maintain a large population of leguminous species (cool, controlled burns reduce legumes and favour Proteaceae) (McCormick 1971). It should be noted that Species Reappearance quadrat number 9 which is not located in a moist site, had a low fire intensity and was burnt just three years prior to the 1994 fire, displayed a vigorous regrowth of *Acacia lateriticola*, suggesting that the fire in this area was still sufficiently intense to achieve successful legume regeneration. (Photo 17). A density of 337 plants per 100 m^2 was recorded for this species in this quadrat in 1998 (compared to just 95 per 100 m^2 for *Hibbertia hypericoides*, another common species in this quadrat).

Of the many species using some form of re-sprouting as a method of survival against fire, the first to re-appear in Bungendore Park were *Macrozamia riedlei* and the two common *Xanthorrhoea* (*X. preissii* and *X. gracilis* although in some plots *X. gracilis* was 5–6 months behind *X. preissii*). Species of Xanthorrhoeaceae and Orchidaceae are also stimulated to flower after fire (Photo 18.). Within six months there were numerous woody perennials regenerating. Five genera in the Proteaceae (*Dryandra, Grevillea, Hakea, Banksia, Petrophile, Synaphea* and *Persoonia*) all had species regenerating commonly. Four species of *Hibbertia* (*H. hypericoides, H. commutata, H. huegelii* and *H.*

amplexicaulis) were widespread by this stage and *Bossiaea ornata*, *Daviesia decurrens*, *Hovea chorizemifolia*, *Kennedia coccinea* and *K. prostrata* represented the Papilionaceae family. *Phyllanthus calycinus*, *Trymalium ledifolium*, *Clematis pubescens*, *Isopogon sphaerocephalus*, *Lasiopetalum floribundum* and *Styphelia tenuiflora* were also common by six months. Of these species, all except *Synaphea petiolaris* persisted through to the final sampling 7 years after the fire (resprouters may survive drought and grazing better than obligate seeders as they have an intact food store root system –) (Hussey and Wallace 1993). Resprouters which were slow to re-appear included species of *Conostylis*, *Dampiera*, *Gompholobium*, *Astroloma*, *Leucopogon* and *Pimelea*, taking 2–3 years to return to the park.

PART 3: FIRE FREQUENCY, REGENERATION MECHANISMS AND FIRE MANAGEMENT STRATEGY

Delfs *et al.* (1987) suggested that resprouters have an advantage over seed regenerating species as they have a well established rootstock to mobilize nutrients. Resprouters are favoured by frequent low intensity fires but, if too frequent, rootstock reserves decrease and they don't reach flowering age (Burrows 1985), so their numbers in the forest would decrease (CALM 1994). Fires which are too frequent or too infrequent produce lowered species diversity (Burrows 2000 b.). They also encourage weed invasion (Fisher 1998., Baird 1984., and Moore and Graham 1985). Fires must not, therefore, be more frequent than the time taken for many plants to reach maturity and set seed and not just to reach flowering stage (Hussey and Wallace 1993). For example, *Dryandra sessilis* flowers after 3–4 years but does not set seed until 8 years after fire (Hussey and Wallace 1993). Up to ten years is needed between fires for some other species to germinate and set seed. Therefore, fires which are too frequent can cause changes to species composition (Australian House of Representatives 1984). Frequent fires can also be responsible for soil deterioration and consequent poor growth of annual and herbaceous geophytes (Baird 1977). The large numbers of geophyte species such as *Chamaescilla corymbosa*, *Burchardia umbellata*, Droseras, Stylidiums and species of *Thysanotus* recorded in this study, especially from quadrats 1,2 and 3 bears testament to the fact that this is not the case in Bungendore Park which has had very infrequent high intensity fires. Long periods of fire exclusion on the other hand can produce a permanent decline in species richness if time between fires is greater than the shelf life of the seed (Burrows 1997). McCaw (1988), reported a decrease in species richness and diversity in the Jarrah forest when the period between fires was > 6 years and a similar trend exists in the Karri forest of South-Western Australia (Western Australian Bushfires Board 1977). Best seed germination depends not on the frequency of the burn alone but on the right combination intensity and season

(Skinner 1984). Therefore, a combination of spring and autumn burns could be desirable (Skinner 1984). It is now generally accepted that a rotational burn cycle which includes different seasons (Burrows 2000 a., and Burrows 1983) is the most likely to maintain habitat and species diversity (Hussey and Wallace 1993 and Western Australian Bushfires Board 1977) and would keep forest fuel loads below 8 tonne/ha which is below wildfire fuel load levels (Burrows 2000 b.). This is supported by the 1984 report on bushfires in Australia (Australian House of Representatives 1984).

Bungendore Park displays a mosaic of fire history (Figure 1) due to the controlled burns which have been executed around its perimeter and the large central area which encompasses many different vegetation types. This area has not been burnt for at least 16 years which has probably helped contribute to the diversity of habitats and species within the park and helped maintain its healthy condition. Furthermore, the fact that the park contains some areas burnt with a low fire intensity will hopefully allow some species not adapted to high fire intensities to survive in these areas and re-colonize other areas later. It was suggested that in local urban reserves, small, unburnt areas be left as a species bank for the recolonization of burnt areas (Australian House of Representatives 1984). Every species behaves differently in response to fire – what is good for one is not good for another (Baird 1983) and so a rotational burn strategy is likely to benefit the majority of species in Bungendore Park.

PART 4: SPECIES DIVERSITY

By six months after the fire, just 30 % of all species recorded during the study period had been observed (Table 8). By the end of 1995, however, after the first post-fire winter, 55% of the total had been listed due to the appearance of many species of herbaceous geophytes such as *Burchardia*

Table 8. Overall Species Diversity.

	Time since 1994 fire				
	Early 1995 (< 6 months)	Late 1995 (6–12 months)	1996 (18–24 months)	3–5 yrs	6–7 yrs
Species (% of total known for park)	16	31	39	33	30
Species (% of total recorded for 7 years)	30	55	70	59	54

Table 9. Individual Quadrat Species Diversity.

Quadrat No.	Total Number of Species				
	Early 1995 (< 6 months)	Late 1995 (6–12 months)	1996 (18–24 months)	3–5 yrs	6–7 yrs
1	16	32	40	39	23
2	13	27	44	41	33
3	11	39	18	36	19
4	14	33	42	36	33
5	9	25	27	25	20
6	N/A	N/A	N/A	N/A	33
7	22	45	46	52	37
8	10	29	30	33	38
9	21	38	47	49	33

multiflora and *B. umbellata*, and many species of *Drosera*, *Stylidium* and orchids. Unlike most geophytes which use some form of underground perennating storage organ to re-sprout, Stylidiums regenerate from seed, explaining why they were slightly slower to re-appear (most not recorded until the second post-fire year) than the other geophyte species. Species diversity reached a peak of 70 %, 2 years after the fire (normally between 3 and 5 years) (Burrows 2000 b.), while orchid numbers were still high and with the appearance of perennial species that had been slower to regenerate.

Rainfall following the fire may have played a part in this rapid increase in species diversity. The 1994 fire was followed by no good rains for a period of 5 months. For example, by the end of the first sampling in March 1995, Bungendore Park had received only 11 mm. Understorey species have small seeds and so cannot survive on seed-stored food reserves. These species soon die off if fire is followed by dry summer (Burrows 1983). Two years of above average rainfall, however, then followed this initial dry spell (53 mm above average for 1995 and 191 mm above average for 1996). Species diversity in Bungendore Park declined after 2 years as short-lived and fire-stimulated species (herbs, some grasses and orchid species) died out. During this period, however, although diversity was declining, numbers of some individual species were increasing. For example, *Hibbertia hypericoides* was recorded from quadrat SR9 on every one of the sampling dates for this quadrat and yet its density went from 5 plants/100m^2 in March 1995 to 25 plants/100m^2 in August of the same year and by August 1998, density was 95 plants/100m^2. This was probably also the case for many other species. A re-sampling after 10–15 years would provide a good indication of the park's true species diversity.

ORCHID SURVEY

Before the fire, a total of 31 orchid

Table 10. Annual orchid species numbers, related to fire-stimulation.

Year	Total no. species	% Fire stimulated	Number of species flowering only after fire
1993	31	48	1
1995	47	49	4
1996	30	46	2
1998	27	37	0
2000	19	47	0

species were known to occur in the park (Table 10). Approximately half of these are fire-stimulated. One species (*Prasophyllum giganteum*) was recorded from the park before the fire and is known to flower only after a summer fire. This plant was, however, recorded in 1994 from an area of the park that had been control burned in 1993.

The 1994 wildfire resulted in an increased number of orchid species for Bungendore Park. Sixteen species, new to the Park, were recorded in 1995 (Table 11 and Appendix 1). Four of these flower only after fire (*Caladenia nana* ssp. *nana*, *Cyanicula ixioides* ssp. *candida*, *Microtis* aff. *alba* and *Prasophyllum hians*). The 1995 sampling also saw greatly increased abundance of many of the fire stimulated species (Photo 19). Of the 23 fire-stimulated species recorded for 1995, eight species (35%) had populations of >20 plants at their recording site whilst only 2 of the 24 species which are not fire-stimulated (8%), had populations in excess of 20 plants (15 of these 24 species – 63%, had populations of less than 10 plants). For example, the Purple Enamel Orchid (*Elythranthera brunonis*) flowers more profusely following a summer fire whilst the Pink Enamel (*Elythranthera emarginata*) is not stimulated by fire. In 1995, populations of purple enamels with >20 were common in the park but only one individual of the pink variety was seen. Many of the fire-stimulated species would probably have been present in the park before the fire but in smaller numbers.

By 1996, the total number of orchid species had dropped to pre-fire levels (30 species). Fewer fire-stimulated species were recorded (14 species compared to 23 in 1995), and many species from the 1993 list such as *Pyrorchis nigricans*, *Cyanicula gemmata*, *C. sericea*, *Diuris setacea* and *Elythranthera brunonis* either failed to return or re-appeared in much smaller numbers. Furthermore, 12 of the 16 new records which had appeared in 1995 (including two of the four "fire-only" species – *Cyanicula ixioides* ssp. *candida* and *Prasophyllum hians*) were not recorded in 1996 (Table 11).

Observations in 1998 and 2000 saw further decreases in overall orchid numbers although a few new records were picked up during this 5 year period – species which may have been present in the park before but not recorded.

Table 11. New records of orchid species (post-fire).

Year	Number of new records	No. species fire stimulated	No. species flowering only after fire	No. of 1995 species not recorded
1993	–	–	–	–
1995	16	8	4	–
1996	3	1	1	12
1998	4	1	0	15
2000	0	0	0	15

Only one of these new records (*Prasophyllum plumaeforme*) is enhanced to flower following a summer fire and none of these new recorded species requires fire to flower. *Microtis* aff. *alba* was the only one of the sixteen new records for 1995 to be seen in the last 5 years of the survey. By the end of the study, *Caladenia flava* ssp. *flava*, *Cyanicula sericea*, *Diuris brumalis*, *D. corymbosa*, *Pterostylis recurva*, *Thelymitra crinita* and *T. macrophylla* were the more common species seen in the park.

Orchids are stimulated to flower after fire due the response of orchid tubers to ethylene gas released from the fire (Dixon 1989). Researchers are still investigating the stimulatory response of fire on orchid species centering on investigations not only into this but also on the nutrients released by ash and changes in mychorrhizal soil fungi.

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Appendix 1. Seven Year Orchid Survey of Bungendore Park

Species	ORCHID SURVEY Common Name	Location	1993	1995 <10	1995 10–20	1995 >20	1995	1996	1998	2000
Caladenia flava ssp *flava*	Cowslip	widespread *	Y			X	Y	Y	Y	Y
Caladenia longicauda ssp *longicauda*	White Spider	SR9	Y	X			Y	Y	Y	
Caladenia macrostylis	Leaping Spider		Y	X			Y	Y		
Caladenia reptans ssp *reptans*	Dwarf Pink Fairy	SR9 *	Y	X			Y	Y	Y	Y
Caladenia uliginosa ssp *uliginosa*	Darting Spider	*	Y		X		Y	Y		
Cyanicula deformis	Blue Fairy	SR9 *	Y			X	Y	Y	Y	Y
Cyanicula gemmata	Blue China	widespread *	Y			X	Y	Y		
Cyanicula sericea	Silky Blue	widespread *	Y			X	Y		Y	Y
Diuris brumalis	Winter Donkey	*	Y	X			Y	Y	Y	Y
Diuris corymbosa	Common Donkey	SR2 *	Y	X			Y	Y	Y	Y
Diuris longifolia	Purple Pansy		Y	X			Y	Y		
Diuris magnifica	Pansy	North of pit 7	Y	X			Y			
Diuris setacea	Bristly Donkey	Just W of pit 10 *	Y			X	Y			
Elythranthera brunonis	Purple Enamel	widespread *	Y			X	Y	Y	Y	Y
Elythranthera emarginata	Pink Enamel	SR9	Y	1			Y	Y	Y	Y
Eriochilus dilatatus ssp *multiflorus*	Common Bunny	pit 5 *	Y		X		Y	Y	Y	Y
Leporella fimbriata	Hare	*	Y				Y	Y		
Monadenia bracteata	South African Orchid		Y		X		Y		Y	Y
Prasophyllum elatum	Tall Leek	SR2 *	Y	X			Y	Y		
Prasophyllum giganteum	Bronze Leek	SR9 only*	Y	X			Y	Y		
Prasophyllum parvifolium	Autumn Leek	SR8	Y	X			Y	Y	Y	
Pterostylis aff. *nana*	Snail	SR9	Y	X			Y	Y	Y	Y
Pterostylis barbata	Bird	pit 5 car park	Y	X			Y	Y	Y	
Pterostylis recurva	Jug	pit 5 car park	Y	X			Y	Y	Y	Y

Pterostylis vittata	Banded Greenhood	SR9	Y	X			Y	Y	Y	Y
Pyrorchis nigricans	Redbeaks	entrance + SR3 *	Y			X	Y			
Thelymitra antennifera	Lemon-scented Sun	Near SR3	Y	X			Y	Y	Y	
Thelymitra benthamaniana	Leopard	Pit 5 and near SR1	Y	X		X	Y			
Thelymitra crinita	Blue Lady		Y		X		Y	Y	Y	Y
Thelymitra macrophylla	Scented Sun		Y				Y		Y	Y
Thelymitra stellata	Star	Localities withheld	Y		X		Y		Y	Y
NEW *for* 1995										
Caladenia hirta ssp *hirta*	Sugar Candy	SR 4 *		X			Y			
Caladenia longicauda ssp *clivicola*	Hill's White Spider	widespread *				X	Y		Y	Y
Caladenia marginata	White Fairy	SR9			X		Y			
Caladenia nana ssp *nana*	Little Pink Fan	betw pit 5 & SR3 only*		X			Y			
Cyanicula ixioides ssp *candida*	White China	south edge of pit 5 only*		1			Y			
Diuris filifolia	Cats Face	Top of pit 5			X		Y			
Diuris laxiflora	Bee	SR2				X	Y	Y		
Diuris micrantha	Dwarf Bee	SR2			X		Y			
Drakea livida	Warty Hammer	top of ridge above Howe St		X			Y			
Lyperanthus serratus	Rattle Beaks	Robin Ramble		X			Y			
Microtis aff. *alba*	Scented Mignonette	SR7								
only*		X			Y	Y				
Prasophyllum aff *elatum*	Crowded Leek	nr SR3 *		X			Y	Y		
Prasophyllum fimbria	Fringed Leek	SR2 usually*			X		Y			
Prasophyllum hians	Yawning Leek	Widespread only*			X		Y			
Prasophyllum ringens	Little Laughing Leek	SR3			X		Y	Y		
Thelymitra pauciflora	Slender Sun Orchid	SR8		X			Y			

ORCHID SURVEY

Species	Common Name	Location	1993	1995 <10	1995 10–20	1995 >20	1995	1996	1998	2000
NEW for 1996–1998										
Caladenia latifolia	Pink Fairies	Wattle Rd.						Y	Y	
Microtis media ssp *media*	Common Mignonette	SR2						Y	Y	Y
Prasophyllum plumaeforme	Dainty Leek	Near pit 5							Y	
Pterostylis aff. *sanguinea*	Crowded Banded Greenhood	SR9							Y	
Pterostylis crispula m.s.	Snail Orchid	Near pit 5							Y	
Spiculaea ciliata	Elbow	SR3							Y	Y
Thelymitra pauciflora	Slender Sun	SR3						Y		

* = fire-stimulated
only* /usually* = flower only/usually after fire
Y = recorded that year
X = number of individuals in 1995